International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Evolution of Single-Particle Energies for N=9 Nuclei at Large N/Z

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We have studied the ^{13}B(d,p)^{14}B reaction in inverse kinematics to better understand the evolution of the properties of single-neutron states in the *sd* shell for neutron-rich N=9 isotones. We have also obtained data for the ^{15}C(d,^{3}He)^{14}B reaction to provide additional information on ^{14}B complementary to that obtained with the (d,p) reaction. The nucleus ^{14}B is the most neutron-rich N=9 isotone that is still particle bound in its ground state, and provides an excellent opportunity to explore the effects of the tensor contribution to the evolution of *sd*-shell effective single-particle energies, the properties of loosely-bound or un-bound states, and to test the predictions of shell-model interactions at the boundary of nuclear stability. The inversion of the relative positions of the $1s_{1/2}$ and $0d_{5/2}$ orbitals when moving from ^{17}O to ^{15}C is behavior is driven largely by the changing tensor interaction between the *p*-shell protons and the *sd* shell neutron, however other effects are also likely to be important, such as halo behavior that arises due to the small neutron binding energy. The very weakly bound first-excited state, should its wave function be dominated by a $1s_{1/2}$ neutron configuration, may be the best-known example of a single-neutron-halo state. As the states of interest are either loosely bound, or unbound with respect to neutron decay, they also pose a challenge to the usual reaction models used to analyze transfer-reaction data.

We have studied ^{14}B using two reactions: neutron adding with ^{13}B(d,p)^{14}B, and proton removal with ^{15}C(d,^{3}He)^{14}B. The experiments were conducted in inverse kinematics using radioactive beams produced using the in-flight method via the ^{14}C(^{9}Be,^{10}B)^{13}B and ^{14}C(d,p)^{15}C reactions at the ATLAS facility at Argonne National Laboratory. The proton and ^{3}He reaction products were detected with HELIOS [1] (the HELIcal Orbit Spectrometer), in coincidence with the recoiling residual nuclei. HELIOS exploits a uniform magnetic field to transport light-charged particles from the target to an array of position-sensitive silicon detectors. This method alleviates many difficulties associated with the study of such transfer reactions in inverse kinematics. Similar experiments have been performed to analyze the properties of *sd*-neutron states in ^{13}B[2], ^{16}C[3], and ^{20}O[4]. The neutron-adding reaction yields relative spectroscopic factors that allow us to construct wave functions for the low-lying excitations in ^{14}B which, for 2^- and 1^- levels, are configuration-mixed states that include both $\pi(0p_{3/2})^{-1}\nu(1s_{1/2})$ and $\pi(0p_{3/2})^{-1}\nu(0d_{5/2})$ contributions. The proton-removal data permit a better isolation of the $\pi(0p_{3/2})^{-1}\nu(1s_{1/2})$ components and together, the results provide a determination of the $1s_{1/2}$ and $0d_{5/2}$ effective single-particle energies in this nucleus that can be compared to other similar nuclei in this region. Experimental results and a comparison of the data to shell-model and *ab-initio* No-Core Shell-Model calculations will be presented.

This work is supported by the U. S. Department of Energy under contract numbers DE-FG02-04ER41320 and DE-AC02-06CH11357, and the U. S. National Science Foundation under grant numbers PHY-02-16783 and PHY-07-58099.

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